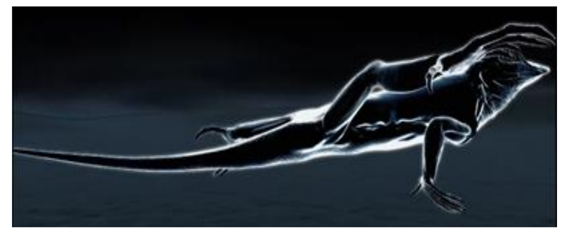
Maximizing Speed for Sand Locomotion using Lizard-Inspired Leg

Team Names: Jose Martinez, Ruben Castro, Nisal Ovitigala, Melissa Klein

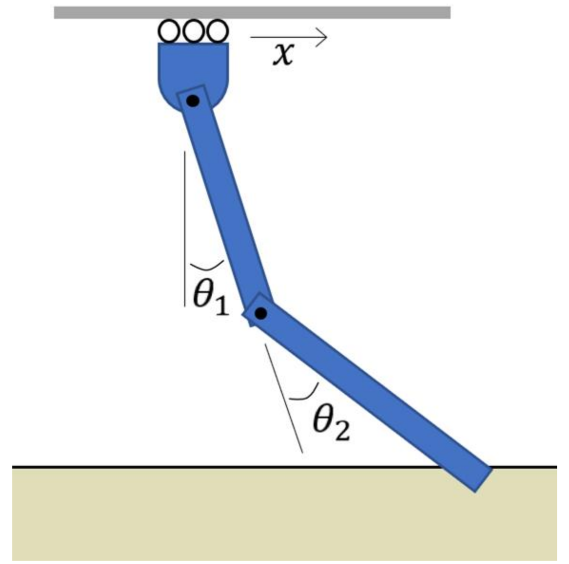
Introduction



- For humans, running in the sand requires **1.6 times** more energy expenditure than running on a hard surface [1]
- **Shovel-Snouted Lizards** move paddle-like back feet in a 360 degree trajectory, being able to reach speeds of about 3 feet/sec, which is over 20 times its body length [2]

Using impedance control on a 2-DOF robotic leg, the “paddle” locomotion strategy is replicated, with the hip joint having 360 degree range of motion.

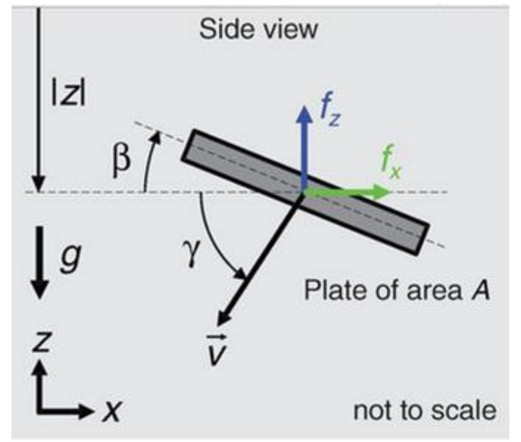
This project aims to explore an optimal 2nd joint **angle θ_2** and **stiffness** that leads to a highest **average speed** of locomotion when utilizing this locomotion strategy.



Sand Modeling

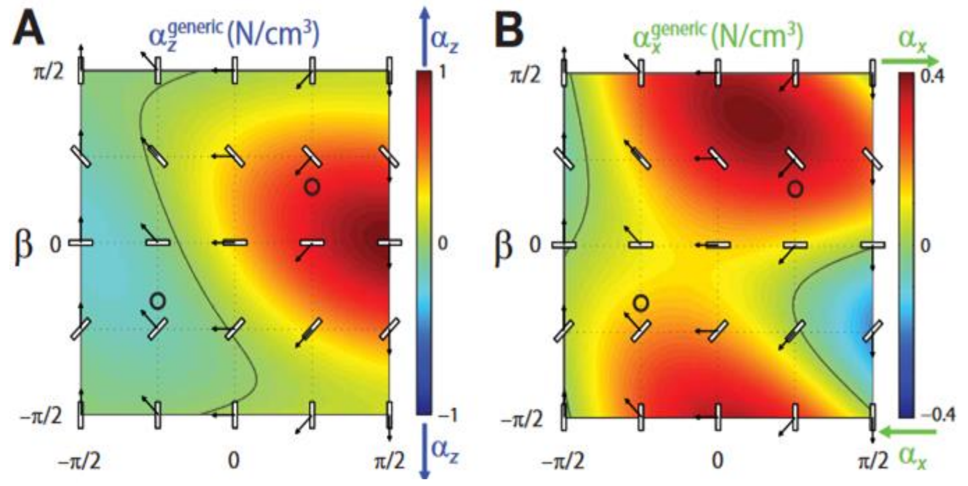
1. Determine β and γ: Attack & Intrusion angles
2. Compute α values in x and z directions from Dan Goldman generic model [3]
3. Determine stress (α * depth)

$$\vec{\sigma}(d, \alpha_x, \alpha_z) = d * \begin{bmatrix} \alpha_x \\ \alpha_z \end{bmatrix}$$



1. Find center of pressure (COP)
2. Sum stresses

$$\vec{F} = \int_0^D \vec{\sigma}(d, \alpha_x(d), \alpha_z(d)) * dd$$

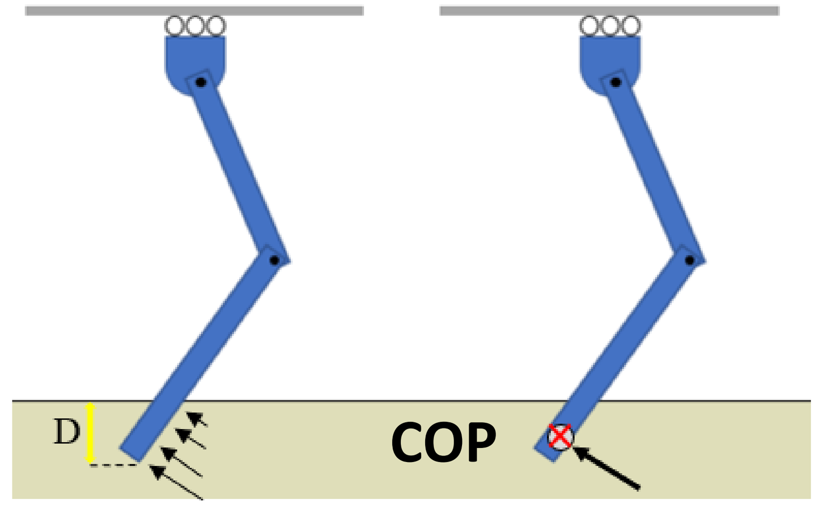


1. Compute generalized forces from transpose of Jacobian at COP

$$\vec{\tau}_{sand} = J_{COP}^T * \vec{F}$$

1. Add into dynamics

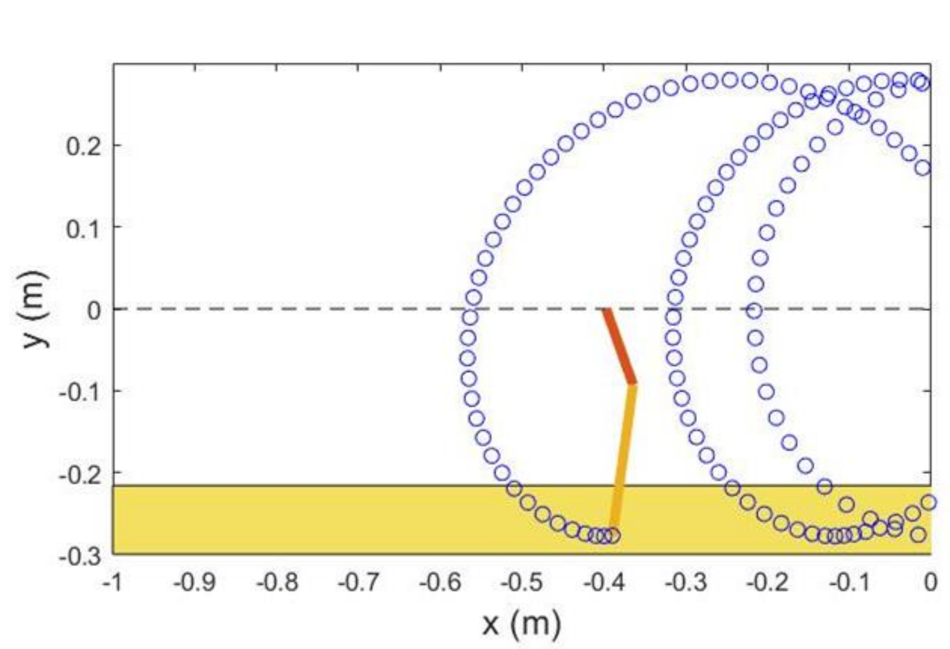
$$M_q\ddot{q} + V_q(q,\dot{q}) + G_q(q) = \tau_{motor} + \tau_{sand}$$

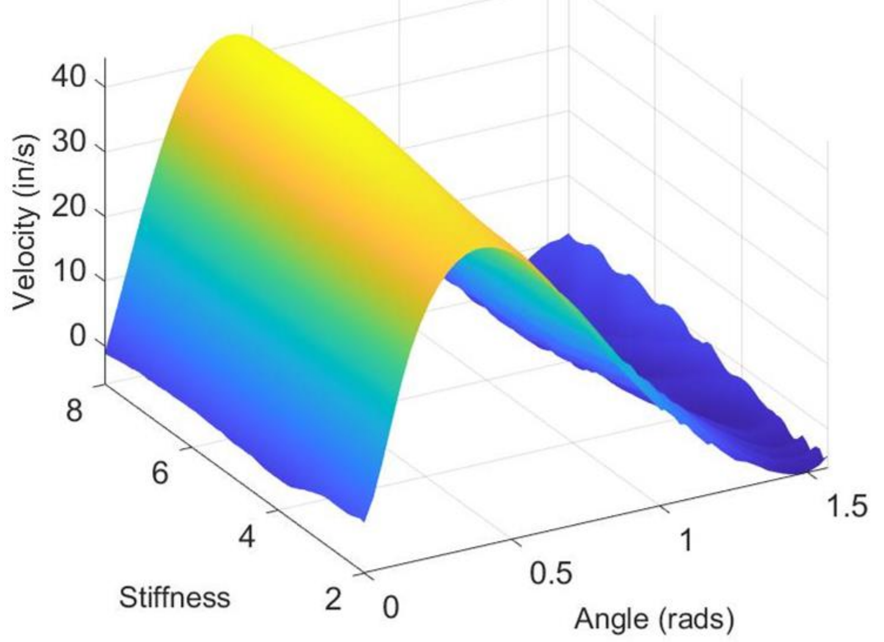


Simulation Results

The simulation incorporated the sand model into its dynamics and was run on a forward Euler algorithm. To control the leg, the first joint was driven with the maximum torque the motor can produce while following its torque-speed curve. The second joint was driven using a PD impedance controller to hold a fixed angle. The simulation was run to find the optimal stiffness value and leg angle for the second joint.

- **Optimal joint angle:** 0.41 rad
- **Optimal stiffness:** 5.6
- Stiffness has minimal impact on the average velocity

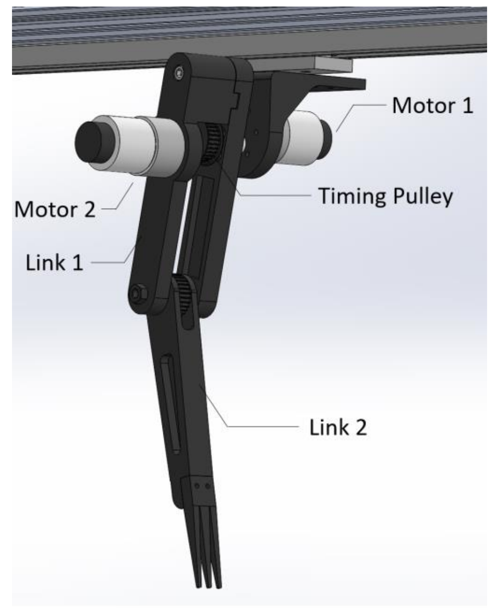




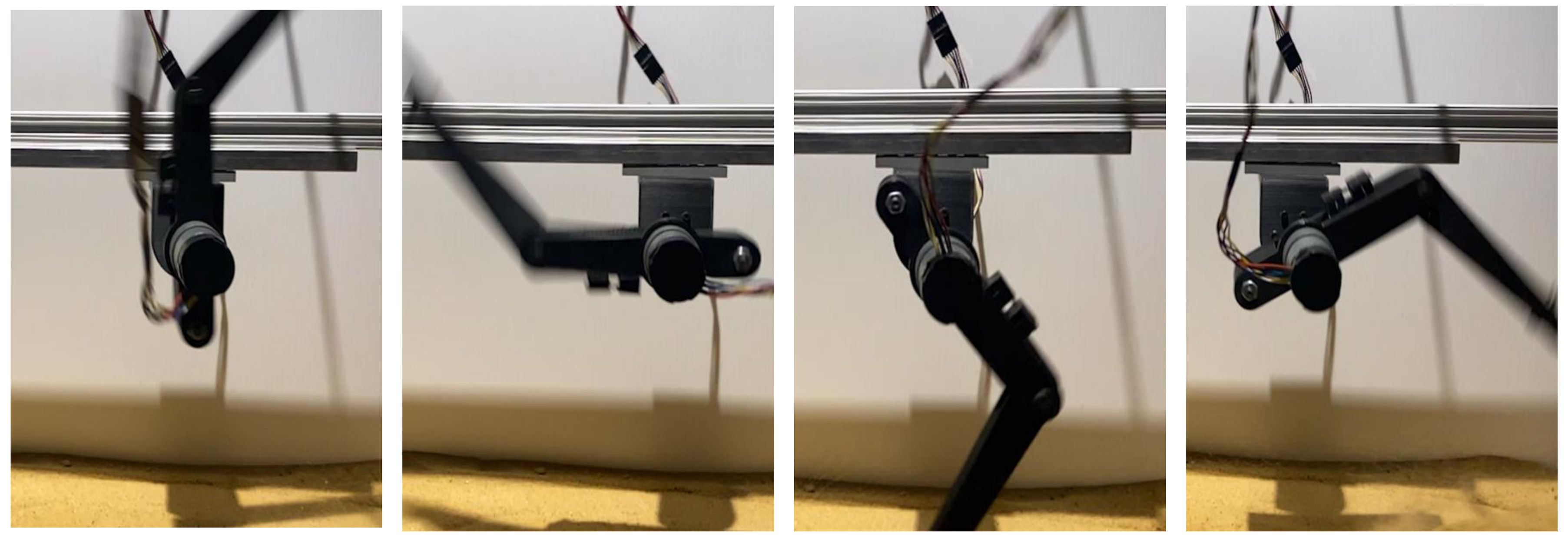
Experimental Methods

2-DOF robotic leg with concentric motors for:

- Full range of motion at hip joint
- Low leg inertia for hip motor to actuate



Used linear slide gantry to support leg weight and allow for motion in X axis. Ran all experiments using 100% duty cycle on hip motor and varying input stiffnesses and angles for second joint. Slow motion video captured for all runs, and frame count used to measure average velocity over track length.

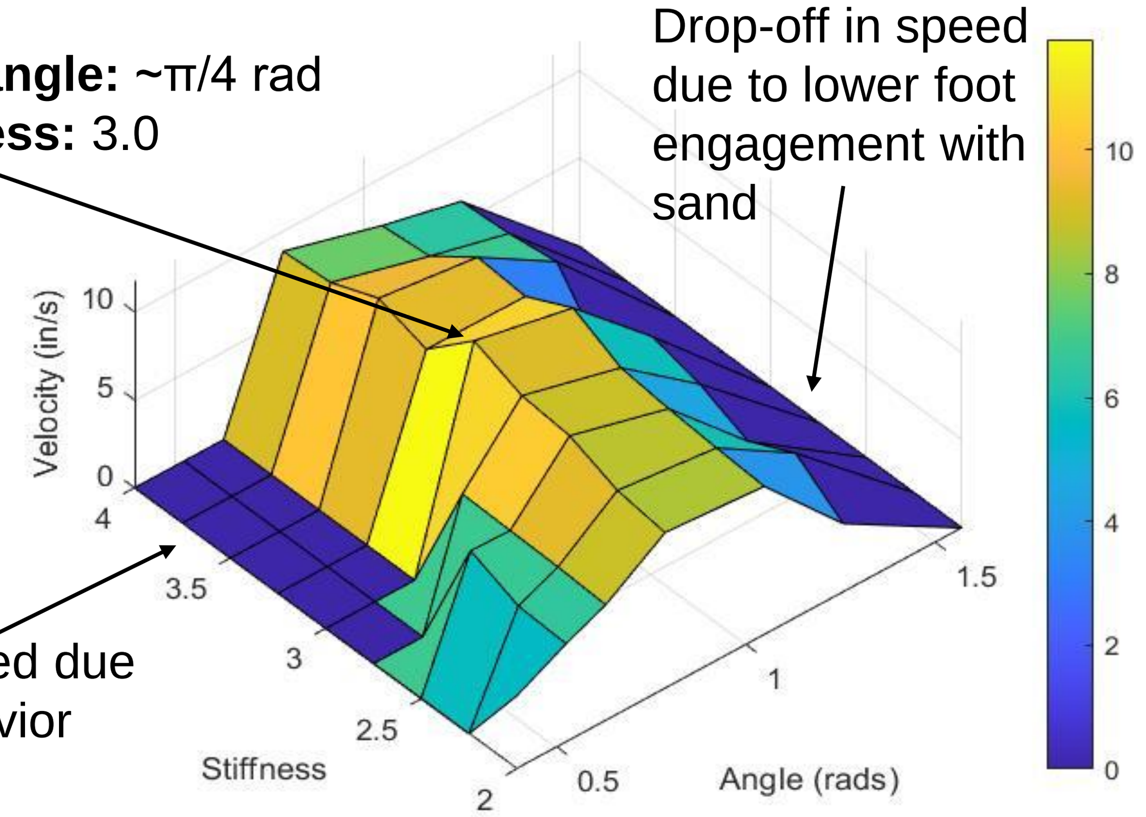


Experimental Results

Optimal joint angle: ~π/4 rad
Optimal stiffness: 3.0

Drop-off in speed due to lower foot engagement with sand

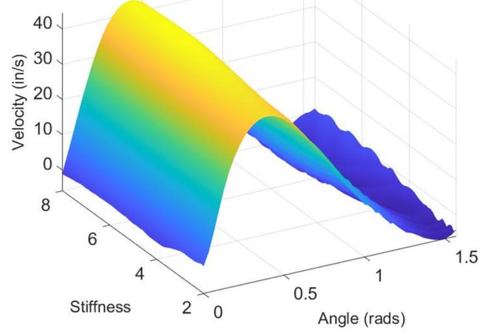
Drop-off in speed due to locking behavior



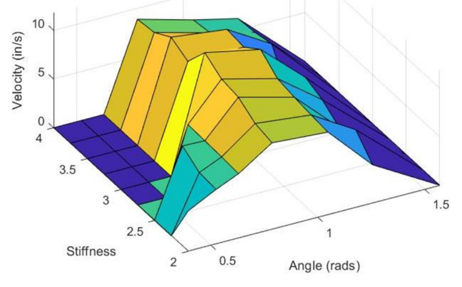
Discussion

- Qualitatively, both experimental and simulation results display a concave contour with a clear maximum angle.
- Maximum velocity in simulation is ~3.8x greater than in experiment
- Disparity in values may be due to:
  - Differences in granularities of sand
  - Friction in experimental setup
  - Linear slide locking & motor torque limit

Simulation



Experiment



Conclusion

1. There exists an optimal setpoint angle for joint impedance control during sand locomotion
   - Experiment: ~π/4, Simulation:~ π/8
2. Minimal correlation between 2nd joint stiffness & maximum velocity
3. Cartesian control & trajectory optimization challenging with current setup
4. Variability in sand medium presents uncertainty in simulation

References

1. Lejeune, T.M. "Mechanics and Energetics of Human Locomotion on Sand." *Journal of Experimental Biology* (1998): 10.
2. Smithsonian. “*Speed Kills: Desert.*” 19 May 2015. Video.
3. Goldman, Li, & Zhang. “A Terradynamics of Legged Locomotion on Granular Media.” *Science* (2013)

We would like to thank the course staff for their guidance and endless support throughout this semester!